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SPATIAL DISTRIBUTION OF MANAGEMENT MEASURES, ANTARCTIC KRILL CATCH AND SOUTHERN OCEAN BIOREGIONS: IMPLICATIONS FOR CONSERVATION PLANNING

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Abstract

Systematic conservation planning for developing marine spatial protection includes analysis of the spatial distribution of fishing activities, existing management and ecological characteristics. This paper assesses the overlap between habitat (bioregion), existing spatial management and Antarctic krill catch in the Southern Ocean. The analysis required standardised information on the location and extent of spatial fisheries management measures, which was delivered through a Geographic Information System (GIS). During the 2010/11 season, 64% of the CAMLR Convention Area was open to fishing for at least one species. There were important differences between pelagic bioregions in terms of the fraction that was open to fishing, and the distribution of catch within the open fraction. For example, only 26% of the main area open to krill fishing has been fished, and this fishing is concentrated in three of the seven bioregions found in the open area. Information on the distribution of catches and catch limits among different bioregions could be used to prioritise protection for bioregions that are currently under-represented in marine protected areas (MPAs). However, conservation planning should take account of uncertainties that result from the different spatial resolution of datasets and the use of long-term averages to identify spatial boundaries.

Introduction

CCAMLR has endorsed the development of a representative system of marine protected areas (MPAs) in the Southern Ocean. This aims to ensure protection for marine habitats and biodiversity, over locations and scales that are appropriate in terms of both conservation benefits and rational use. A conservation measure (CM) agreed by the Commission in 2011 (CM 91-04) sets out a general framework for establishing MPAs, stating that:

'CCAMLR MPAs shall be established on the basis of the best available scientific evidence, and shall contribute, taking full consideration of Article II of the CAMLR Convention where conservation includes rational use, to the achievement of the following objectives:

(i) the protection of representative examples of marine ecosystems, biodiversity and habitats at an appropriate scale to maintain their viability and integrity in the long term...' (CCAMLR, 2011).

There are many approaches to the design of representative MPAs, most of which require a characterisation of marine habitats and ecosystem processes to determine the different regions and habitat types that must be represented (e.g. Kelleher et al., 1995; Roff and Taylor, 2000; Roberts et al., 2003; Lourie and Vincent, 2004). There is also a need to consider existing management measures and human uses of the marine environment (e.g. Lombard et al., 2007; Smith et al., 2009). The CCAMLR Scientific Committee has identified systematic conservation planning (SCP) (Margules and Pressey, 2000; Pressey et al., 2007; Ardron et al., 2010) as one feasible approach to the design of a representative system of MPAs. The objective of this approach is to design and implement protected areas that comprehensively represent the biodiversity of each region, using a transparent process to select areas that meet clear conservation goals (Ardron et al., 2010). Various authors have described individual steps for this process with slightly different formulations (e.g. Margules and Pressey, 2000; Pressey et al., 2007; Ardron et al., 2010), the core elements of which are summarised here in the context of a fished marine ecosystem:

(i) compile data on the biodiversity and other features of the planning region, identifying which datasets are most useful for providing summary or surrogate information across the region

(ii) set conservation objectives, which may include quantitative targets for species occurrence, minimum size etc., as well as qualitative targets such as preferences for connectivity between conservation areas

(iii) review existing conservation and management areas within the planning region, and the extent to which these meet the defined objectives

(iv) select new conservation areas to be considered for addition to the suite of existing areas, with the aim of meeting the defined conservation objectives

(v) implement conservation actions, for example MPA designation or other appropriate management.

The data compilation (step i) and review (step iii) stages of the SCP process require high quality, spatially resolved information on biodiversity and ecosystem characteristics, existing human activities, conservation measures and management areas. Analysis of the distribution of fishing activities is also important in informing the data compilation stage (step i), which aims to identify areas that can meet the defined conservation objectives with minimal displacement of these activities. In order for such information to be incorporated into MPA planning on a scientific basis, it must be available at scales that are appropriate to the scale at which MPA management occurs (Stevens, 2002). Some authors have employed a hierarchical series of spatial scales as a framework within which to identify and map marine environments for this purpose (Table 1). This type of hierarchical system is useful for categorising the spatial scales of different types of information that can inform the SCP process, including data on habitat types, fisheries catch and existing spatial management.

This paper demonstrates how standardised geographic information on spatial management can be used with data on fisheries catch and bioregions to assist with conservation planning. The objective is to assess the overlap between habitat, existing spatial management and actual fishing. Spatial management data were standardised within a geographic information system (GIS) and combined with the Grant et al. (2006) pelagic bioregionalisation as an indicator of habitat, and catch data for Antarctic krill, *Euphausia superba* (hereafter krill), in the Scotia Sea and southern Drake Passage (Subareas 48.1 to 48.4) (Figure 1a) provided by the CCAMLR Secretariat. These combined data were used to assess:

(i) the location and extent of existing spatial management areas

(ii) the distribution of catch limits across spatial management areas

(iii) the distribution, across both spatial management areas and bioregions, of actual krill catch in the Scotia Sea and southern Drake Passage

(iv) the distribution of pelagic bioregions across spatial management areas (and thus the proportion of those bioregions that are currently open to fishing)

(v) scales of spatial correspondence between datasets.

Methods

Data

This analysis used selected datasets that are representative of the available information on pelagic habitat types, krill catches and spatial management measures.

A pelagic bioregionalisation of the Southern Ocean (Grant et al., 2006) was endorsed by the Scientific Committee in 2007 as providing a basis for informing spatial management in the Convention Area (SC-CAMLR-XXVI, paragraph 3.75). This classifies the Southern Ocean into 14 bioregions, on the basis of physical environmental characteristics including depth, sea-surface temperature and nutrient levels, at a regional (meso) to continental (macro) scale. A recently updated version of the pelagic bioregionalisation (Raymond, 2011) is broadly consistent with the characterisation of Grant et al. (2006). Such classifications are useful in summarising habitat types, and therefore supply one component of the range of ecological and biodiversity information required to undertake effective SCP.

The krill fishery in the Scotia Sea and southern Drake Passage accounted for 92% of the total Southern Ocean catch of all species in 2010/11 (CCAMLR, 2012). Information on the distribution of fishing activities can be obtained from commercial catch data. Previous analyses have shown that patterns of krill fishing in Scotia Sea and southern Drake Passage (Everson and Goss, 1991; Kasatkina and Ivanova, 2003; Hill et al., 2009) and in the Indian and Pacific sectors (Ichii, 1990), are broadly similar, with fishing concentrated on the continental shelf, close to the shelf break, and in frontal zones. The analyses performed in this study used weighted krill catch data for the Scotia Sea and southern Drake Passage (Subareas 48.1 to 48.4), aggregated for all seasons (1995 to 2010) and obtained from the CCAMLR Secretariat. These data are resolved to fine-scale rectangles (FSRs: $1° \times 0.5°$). They are based on haul-by-haul catch data, but are rescaled to sum to the aggregated catch by subarea. The haul-by-haul data are reported during the fishing season by individual fishing vessel operators while the aggregated catch by subarea is the official information that is reported annually by CCAMLR Members and is available in the *CCAMLR Statistical Bulletin* (CCAMLR, 2012).

Information on existing conservation and management measures is contained in conservation measures agreed by the CAMLR Commission. These measures apply to various types and sizes of management area (Table 2). To date there has been no central repository of standardised information on the spatial application of conservation measures and the areal coverage of management areas. A GIS and supporting contextual information were therefore developed to store and deliver information about the limits of spatial management areas and the spatially relevant conservation measures that apply to them (Fretwell et al., 2011). The contextual information, held as attributes within the GIS data includes, for example, the implementation dates for conservation measures. The GIS database covers the entire CAMLR Convention Area (35 688 478 km^2; equivalent to around 10% of the world's ocean surface). It includes information on all spatial management areas and the associated conservation measures that were in force for the 2010/11 fishing season (CCAMLR, 2010).

The main type of management area used by CCAMLR is the statistical reporting area or subarea. These areas are internationally recognised, including by the UN Food and Agriculture Organisation (FAO). Smaller management areas, including small-scale research units (SSRUs) are also designated in some subareas. Conservation measures can also designate MPAs. One MPA is currently designated, and proposals for others are being developed (SC-CAMLR-XXX, paragraph 5.28). The database also includes the small-scale management units (SSMUs) devised for spatially subdividing the krill catch limit in the Scotia Sea and southern Drake Passage (SC-CAMLR, 2002; Hewitt et al., 2004; Trathan et al., 2008). These SSMUs are described in CM 51-01, although CCAMLR has not yet set any SSMU-scale catch limits.

The various types of management area are assigned to four separate data layers in the GIS, as detailed in Table 2 which also lists the sources of information used to generate each layer. The polygons in each data layer have been given attributes describing all of the spatially relevant conservation measures in force, including species-specific catch restrictions.

For the development of the database, and the analyses performed in this study, we used ESRI ArcMap Version 9.3.1. All data are spatially referenced and projected in Lambert equal area projection. This facilitates accurate and comparable area calculations throughout the CCAMLR area. Each shapefile has been clipped to an accurate coastline dataset which was derived from two sources: the Antarctic coastline was taken from the Antarctic Digital Database Version 5 (1:1 000 000 data) (SCAR, 2010), whilst the sub-Antarctic was taken from the Global Bathymetric Chart of the Oceans (GEBCO) 2008 (IOC et al., 2008). This combined dataset provides an accurate representation of both the Antarctic coast and all sub-Antarctic islands within the CCAMLR area. These datasets are versioned and can be updated in a transparent manner if necessary. Following endorsement by CCAMLR's Working Group on Ecosystem Monitoring and Management at its meeting in 2012, the GIS database is available for the use of all CCAMLR Members (SC-CAMLR, 2012) from www.ccamlr.org/node/76194. Data are available in the GIS as shapefiles that are compatible with most GIS software, and as comma separated variable (CSV) files for other applications.

Results

Figures 1(a) to 1(c) demonstrate the types of spatially resolved information that can be displayed using the GIS database. These data layers can be incorporated into other maps and spatial analyses, and used to generate spatially derived parameters such as management area size, distances between features, or proportions of areas with particular characteristics. Such outputs have particular relevance for informing the review stage (step iii) of the SCP process detailed above. The database can also be used to store information on MPAs that have been proposed or implemented (step v), providing an up-to-date baseline against which new MPA proposals can be considered and the future development of a representative system of MPAs can be evaluated. The following sections describe the distribution of fishing and management relative to ecological structure, with particular focus on scale-matching between datasets.

Location and extent of existing spatial management areas

Figure 2 shows the spatial extent of conservation measures that allow fisheries for toothfish (*Dissostichus* spp.), mackerel icefish (*Champsocephalus gunnari*), krill and crabs (*Paralomis* spp.), as set out by CCAMLR's *Schedule of Conservation Measures in Force 2010/11*. During the 2010/11 fishing season, 64% of the CCAMLR area was open to directed fishing (i.e. had a catch limit of >0 for at least one species). Most subareas were open for only a single fishery, with 27% of the CCAMLR area open to krill fishing, and 45% open to toothfish fishing. Only 8% of the total CCAMLR area was open to fishing for more than one species, with Subarea 48.3 (3% of the total area) the only management area open to fishing for all of the four major taxa (krill, toothfish, icefish and crabs).

Distribution of catch limits across spatial management areas

The database also allows mapping and visualisation of the attributes of management areas, including catch limits for each fishery (Table 3), allocated on the basis of statistical subareas (Figure 1a) or SSRUs (Figure 1c). Catch limits for each of the fisheries shown in Figure 2 are unevenly distributed between statistical subareas, due to the differences in occurrence or abundance of target species, data availability and level of fishing interest in different regions. For example, 65% of the combined catch limit for krill across the CCAMLR area is allocated to four subareas in Area 48, although these account for only 35% of the total area open for krill fishing. In the 2010/11 fishing season, the trigger level in Subareas 48.1 to 48.4 (the effective catch limit for krill until spatial subdivision of the regional catch limit has been agreed) was equivalent to 7% of the combined catch limit for krill across the CCAMLR area.

Distribution of pelagic bioregions across spatial management areas

All of the statistical subareas and many of the smaller management areas (SSRUs, SSMUs and MPAs) contain more than one pelagic bioregion (Figure 3). Statistics on the distribution of pelagic bioregions across statistical subareas are provided in Table 4.

All subareas contain between three and six pelagic bioregions. There is, however, a marked difference in the extent to which these physical environmental characteristics are represented in different spatial areas (Figure 4). Bioregions 1, 2, 8, 9 and 10 each cover less than 3% of the total Convention Area, and occur in four or fewer subareas (of a total of 18 subareas). Bioregion 7 (Antarctic shelf slope) occurs in half of all subareas, but it accounts for only 1.3% of the Convention Area. Bioregion 6 (Antarctic shelves) similarly occurs in two-thirds of all subareas, but with relatively low coverage in terms of area. Bioregions 3 (Polar Front), 4 (Southern Antarctic circumpolar current (ACC) Front) and 5 (Antarctic open ocean) are distributed across large spatial areas and are present in around three-quarters of all subareas. However, bioregion 13 (Weddell gyre and Ross Sea banks) occurs across large areas in only two major locations, and of the four largest bioregions (each covering more than 10% of the Convention Area), it is the only one which does not have a circumpolar distribution.

Table 5 shows the spatial extent of permitted fisheries and existing MPA coverage for the six largest bioregions in the Convention Area. The only existing MPA in the CCAMLR area (South Orkney Islands southern shelf) covers less than 2% each of the Antarctic shelves and Weddell and Ross gyres bioregions. There is a marked difference in the extent of areas open to fishing for toothfish within different bioregions. For example, 94% of the Antarctic shelf/slope bioregion is open to toothfish fishing, compared to 32% of the Weddell and Ross gyres bioregion. The proportions of bioregions open to krill fishing are generally smaller, ranging from 17% of the Weddell and Ross gyres bioregions to around one-third of the Southern ACC front, Antarctic open ocean and Antarctic shelves bioregions.

Figure 5(a) demonstrates the distribution of bioregions within management areas at a finer scale, for the four subareas within Area 48 that are open to krill fishing. The area covered by each bioregion differs markedly between the four subareas. The Weddell gyre bioregion is the most extensive bioregion in Subareas 48.2 and 48.4, while Subarea 48.1 is dominated by the Antarctic shelf bioregion. Subarea 48.3 is the most northerly of the four subareas, and is dominated by the Southern ACC Front and the Polar Front bioregions. It also contains parts of the Sub-Antarctic Front and Kerguelen bioregions which do not occur in the other three subareas. The unclassified FSRs are those located in areas for which no bioregion is defined. These areas tend to be located close to the coast, and were not classified in the pelagic bioregionalisation because input data (particularly nutrient data) were unavailable (Grant et al., 2006). Most of the unclassified areas are surrounded by, or adjacent to, the Antarctic shelves bioregion, and it is therefore reasonable to assume that most of them could also be included within this bioregion. The largest number of unclassified FSRs is found in Subarea 48.1, which also contains proportionately more of the Antarctic shelves bioregion than the other three subareas.

Distribution of catch across management areas and bioregions

Figure 5(b) shows the distribution of krill catch across bioregions in Area 48 (for the four subareas open to this fishery), in terms of the number of FSRs in which the total reported catch (1995 to 2010) is greater than zero. Two of the seven bioregions found in this area have never been fished. Although the total number of FSRs is approximately the same in each of the four subareas, the numbers of fished FSRs within each subarea are very different (50% in Subarea 48.1, compared to 3% in Subarea 48.4) (Figure 6). In total, only 26% of the FSRs in Subareas 48.1 to 48.4 have been fished, although all are open to the fishery.

Fished FSRs are relatively evenly distributed across the bioregions within each subarea. However, the distribution of bioregions and the proportion of fished FSRs changes between subareas and so the overall distribution of fished FSRs across bioregions is uneven (Figures 5(b) and 6). The Antarctic shelves, Antarctic open ocean and unclassified bioregions together account for between 64% and 75% of fished FSRs in Subareas 48.1, 48.2 and 48.4. None of these bioregions occur extensively in Subarea 48.3 where the most fished bioregion is the Southern ACC Front, which accounts for 67% of the fished FSRs. Actual catches are not distributed evenly between the fished FSRs. Some FSRs may have been fished only once, while others have large catches reported every year. These differences can be demonstrated at a coarse resolution using aggregated historical krill catch data (Figure 7), which shows areas with large aggregated catches around South Georgia, the South Orkney Islands and the South Shetland Islands.

Total catches cannot be assigned with certainty to specific bioregions, because aggregated data do not distinguish specific locations within FSRs. The difference between the maximum estimated catch for each bioregion (catches summed across any FSRs where that bioregion occurs) and the minimum estimated catch (catches summed only across FSRs where that bioregion occurs exclusively) can be up to four orders of magnitude.

Discussion

Combining spatially resolved information on conservation measures in force across the Convention Area with data on bioregions and fishery catches has allowed examination of the relative spatial distribution of fishing activities, existing management and ecological characteristics. The ability to provide spatial descriptions of krill fishing in the context of systematic conservation planning will be beneficial in progressing CCAMLR's future work on both MPA design and the orderly development of the fishery.

During the 2010/11 season, 64% of the CCAMLR area was open to directed fishing for at least one species. Although in practice this means that 46% of the CCAMLR area was closed to fishing during the 2010/11 season, the absence of a current catch limit (or a catch limit of 0) in a particular management area does not provide long-term protection equivalent to that of an MPA, or imply any form of systematic planning for the conservation of biodiversity. Catch limits are unevenly distributed between the 18 statistical subareas, due to the differences in the known occurrence of the species in that area, the level of fishery interest (which is affected in turn by information, accessibility and fishing history), and the availability and quality of relevant data (Kawaguchi and Nicol, 2007).

Management measures such as catch limits are resolved at a coarser scale than the scales at which fisheries actually operate. This is illustrated by the fishery for krill in Subareas 48.1 to 48.4, where only 26% of reporting cells (fine-scale rectangles, all of which are open to fishing) have ever been fished, most of which are in Subarea 48.1 (the southern Drake Passage). Similarly, Kasatkina and Ivanova (2003) noted that during the years of highest recorded fishing activity, the Soviet fleet operated in an area only 8–9% of the total size of Subareas 48.2 and 48.3. Although krill fishery management measures are implemented at a relatively coarse spatial scale, the distribution of actual fishing is related to the distribution of krill within the managed area (Hill et al., 2009), and catches tend to be concentrated on specific bioregions. Previous analyses have identified the continental shelf, shelf break and frontal zones as the major focus of commercial krill fishing activities (Everson and Goss, 1991; Kasatkina and Ivanova, 2003; Hill et al., 2009), and the analysis in this paper shows similar patterns in terms of the distribution of catches across pelagic bioregions.

Fishing operations tend to occur at the site (pica) scale, whereas fisheries catch data may be reported or aggregated to a local (micro) or even regional (meso) scale. Conservation and management measures in the CCAMLR area are generally implemented at a regional (meso) scale. The existing South Orkney Islands southern shelf MPA is at the lower end of the meso-scale (~100 km in linear boundary extent), and is currently one of the largest MPAs in the world (Toropova et al., 2010). However, proposals are now in development for significantly larger MPAs in the Ross Sea and East Antarctica (~1 000 km in linear boundary extent) (SC-CAMLR-XXX, paragraphs 5.30 to 5.66).

The collation of information on the spatial extent of existing fishing activities, and conservation and management measures in force, is a key part of determining where MPAs should be established to achieve the maximum conservation benefits in accordance with Article II of the CAMLR Convention. Statistics on the environmental characteristics of different subareas provide an indication of how different pelagic habitats are managed across the CCAMLR area (Figure 4). The proportion of each bioregion that is currently protected within an MPA (Table 5) demonstrates the need for improved geographic coverage and habitat representation in protected areas. This provides important background information against which proposals for new MPAs within specific bioregions can be evaluated, and could be used to identify gaps in existing protection or management. This would help to prioritise the development of MPAs within bioregions that are currently under-represented in the protected areas system, or which occur only in limited areas.

There is also a marked difference between bioregions in terms of the extent to which they are open to fishing. For example, 10% of the sub-Antarctic bioregion is open to fishing for toothfish, compared to 94% of the Antarctic shelf slope bioregion (Table 4). Although these statistics provide an indication of the distribution of bioregions under particular forms of management, they do not necessarily reflect actual fishing or distribution of catch across these bioregions. The assessment of total catch per bioregion using data aggregated by fine-scale rectangles can provide some insight into the distribution of catches across different habitats. However, there remain uncertainties associated with the assignment of reported catches to individual bioregions. A spatial reporting unit for catch data does not necessarily fit neatly into a single bioregion. Haul-by-haul data would provide a better understanding of the spatial distribution of catches. However, assigning individual catches to bioregions would require site (pica) scale data to be integrated with regional (meso) scale bioregions, introducing potential issues of scale mismatch. In addition, the variables which characterise bioregions change over time. Consequently, a bioregion defined on the basis of long-term (up to 30 years) averages of time series (Grant et al., 2006) might not represent the environmental conditions at a particular fishing location over a shorter time-scale. The identification of representative protection for specific bioregions must therefore include consideration of other regional differences in ecology and environmental characteristics, to ensure that all relevant scales are captured. Comparison of the present results with updated bioregionalisations (e.g. Raymond, 2011) could provide insights into the potential implications of broad-scale changes in the pelagic environment (SC-CAMLR, 2011, paragraph 2.8) for conservation planning.

There are various potential criteria for prioritising bioregions for protection. These criteria could, for example, prioritise: (i) bioregions that are not currently represented within the MPA system (Table 5: bioregions 2, 3, 4, 5 and 7), (ii) bioregions that have the greatest proportional area open to fishing (Table 5: bioregions 4, 5 and 13), or (iii) bioregions that are actually fished to the greatest extent (Figure 5(b) identifies bioregions 4, 5 and 6 as those most affected by the regional krill fishery, although the effect may be different at a circumpolar scale). Of these criteria, (i) appears the most informative in terms of creating a fully representative system of MPAs. Criteria (ii) and (iii) must also be considered, both in terms of the potential threats to those bioregions and the aim of minimising the displacement of regulated and legal fishing activities. Based on these considerations, it is suggested that bioregions 4 and 5 (Southern ACC Front and Antarctic open ocean) should be prioritised for the selection of new protected areas to contribute to a representative system of MPAs. Multi-criteria decision making, supported by high quality spatial information (e.g. using Marxan or other decision-support software; Grant et al., 2009), can help to balance considerations of the full suite of habitat and ecological characteristics with existing management and human activities to facilitate selection of the most efficient protection measures.

This study has demonstrated some of the benefits of using a GIS to deliver standardised spatially resolved data. CCAMLR is currently developing a web-based GIS. This should be a valuable resource for conservation planning and for other applications by a range of stakeholders, including the CAMLR Commission, Scientific Committee and working groups; the CCAMLR Secretariat; researchers investigating Southern Ocean ecosystems; the fishing industry; and enforcement personnel. The inclusion of the datasets used in the current analysis, and additional datasets such as historical conservation measures, and the location and status of existing protected or managed areas would allow these stakeholders to address a diverse range of queries. For example, the CCAMLR MPA Workshop in 2011 suggested that periodic updates should be made to the pelagic regionalisation analysis (e.g. Raymond, 2011) to assist in summarising broad changes in the pelagic environment, and that such updated results could be made available as part of a GIS database (SC-CAMLR, 2011). Information could also be included on other spatial management tools such as vulnerable marine ecosystem risk areas determined by the CCAMLR Secretariat, and marine Antarctic Specially Protected and Specially Managed Areas (ASPAs and ASMAs) designated under the Protocol on Environmental Protection to the Antarctic Treaty.

With appropriate datasets, a consolidated GIS could supply easily accessible baseline data against which new MPA proposals can be considered and the future development of a representative system of MPAs can be evaluated. Although the analysis in the current paper used a circumpolar bioregionalisation, more detailed finer-scale bioregionalisations might be more appropriate for regional conservation planning. It would be appropriate to incorporate the results of such bioregionalisations into the forthcoming CCAMLR GIS as they are developed.

Conclusion

Standardised spatial management information is useful for determining the extent to which human activities are permitted across the CCAMLR region, and the areas in which these activities are not currently allowed to take place. Such information has significant utility in SCP, but caution must be exercised in summarising and integrating data sources resolved to different spatial scales. Scales of management are different to scales of fishery operations, creating potential issues for the management of fishing impacts on different habitat types. There is heterogeneity in the spatial overlap between habitats, catch limits and actual catch. An understanding of where and why these overlaps occur is important in the SCP process, to ensure that protected areas can be selected to meet conservation objectives with minimal cost to rational use.

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Table 1: Hierarchy of spatial scales as a framework for MPA planning (adapted from IMCRA Technical Group, 1998 and Stevens, 2002).

Scale	Linear extent	Units
Macro-scale	1000s of km	Continental provinces
Meso-scale	100s of km	Regions
Micro-scale	10s of km	Local units
Pica-scale	<10 km	Sites

Table 2: Database layers describing CCAMLR management areas. FAO – Food and Agriculture Organization of the United Nations.

Layer		Description	Sources
	CAMLR Convention Area boundary	The CAMLR Convention Area includes the entire Southern Ocean ecosystem to the south of an approximation of the Antarctic Polar Front.	CAMLR Convention, Article I
1	CCAMLR (and FAO) statistical subareas	Large-scale areas for catch reporting based on general oceanographic conditions and biological characteristics, or thought to contain relatively discrete populations of target species. Designed to allow reporting of fisheries data for individual stocks, and implementation of management measures on a stock-by-stock basis (Figure 1a).	Proposed in original form in FAO (1976); further subdivision proposed in Everson (1977).
2	Small-scale management units (SSMUs)	SSMUs are designed to be used for subdividing the krill catch limit in Subareas 48.1 to 48.4. Based on predator foraging ranges (Figure 1b).	Subarea 48.1 to 48.3 SSMUs defined in WG-EMM (SC-CAMLR, 2002). Subarea 48.4 SSMUs defined in Trathan et al. (2008).
3	Small-scale research units (SSRUs) and other spatial fisheries management units	SSRUs are designed to allow implementation of specific restrictions and research requirements for new and exploratory fisheries. (Figure 1c) They may be defined on the basis of features such as bathymetry, location of fishery, distribution of target and by-catch species, and impact of sea-ice on fishing practices. Management units are also defined in some other fisheries for the subdivision of catch limits or other management purposes (Figure 1c).	Data provided by the CCAMLR Secretariat. Original sources include Hanchet (2003) and SC-CAMLR (2003) for Subarea 88.1 SSRUs.
4	Marine Protected Areas (MPAs)	Areas designated for special protection of biodiversity (Figure 1c).	Conservation Measure 91-01

Table 3: Catch limits for toothfish, icefish, krill and crabs, subject to seasonal limits and closures in 2010/11. This extension of a table shown in CCAMLR (2010) was generated by querying the GIS database. SSRU – small-scale research unit; MPA – marine protected area; NJ – national jurisdiction; X – fishery not open.

Subarea/ division	SSRU or other management unit	Catch limit (tonnes)			
		Krill	Toothfish	Icefish	Crabs
48.1	Whole subarea	5 610 000[a] (Trigger level = 620 000)	X	X	X
48.2	SO Southern Shelf MPA	X	X	X	X
	Rest of subarea	5 610 000[a] (Trigger level = 620 000)			
48.3	A	5 610 000[a]	0	2 305	1 600
	B	(Trigger level = 620 000)	900		
	C		2 100		
	Rest of subarea		0		
48.4	N	5 610 000[a]	40	X	X
	S	(Trigger level = 620 000)	30	X	X
	Rest of subarea		0	X	X
48.5	Whole subarea	X	X	X	X
48.6	A	X	200[c]	X	X
	B		200[d]		
	C		200[d]		
	D		200[d]		
	E		200[d]		
	F		200[d]		
	G		200[c]		
58.4.1	A	440 000[b]	0	X	X
	B		0		
	C		100		
	D		0		
	E		50		
	F		0		
	G		60		
	H		0		
58.4.2	A	2 645 000[b]	30	X	X
	B	(Trigger level = 452 000)	0		
	C		0		
	D		0		
	E		40		
58.6	Outside NJ	X	X	X	X
58.7	Outside NJ	X	X	X	X
58.4.3a	Outside NJ	X	86	X	X
58.4.3b	A outside NJ	X	0	X	X
	B		0		
	C		0		
	D		0		
	E		0		
58.4.4	Outside NJ	X	X	X	X
58.5.1	Outside NJ	X	X	X	X

(continued)

Table 3 (continued)

Subarea/ division	SSRU or other management unit	Catch limit (tonnes)			
		Krill	Toothfish	Icefish	Crabs
58.5.2	Outside NJ	X	X	X	X
	Rest of subarea		2 550	78	
58.6	Outside NJ	X	X	X	X
58.7	Outside NJ	X	X	X	X
88.1	A	X	0	X	X
	B		372[e]		
	C		372[e]		
	D		0		
	E		0		
	F		0		
	G		372[e]		
	H		2 104[f]		
	I		2 104[f]		
	J		374[g]		
	K		2 104[f]		
	L		374[g]		
	M		0		
88.2	A	X	0	X	X
	B		0		
	C		214[h]		
	D		214[h]		
	E		361		
	F		214[h]		
	G		214[h]		
	North of 65°S		0		
88.3	Whole subarea	X	X	X	X
Total Southern Ocean		8 695 000	9 811	2 383	1 600

[a] Krill catch limit divided across Subareas 48.1, 48.2, 48.3 and 48.4. Trigger level in force until catch limit is allocated between smaller management units.
[b] Krill catch limits in Divisions 58.4.1 and 58.4.2 are both subdivided between east and west. Trigger level in force in Division 58.4.2 until catch limit is allocated to smaller management units.
[c] Toothfish catch limit divided across SSRUs A and G (north of 60°S) in Subarea 48.6
[d] Toothfish catch limit divided across SSRUs B, C, D, E and F (south of 60°S) in Subarea 48.6
[e] Toothfish catch limit divided across SSRUs B, C and G in Subarea 88.1
[f] Toothfish catch limit divided across SSRUs H, I and K in Subarea 88.1
[g] Toothfish catch limit divided across SSRUs J and L in Subarea 88.1
[h] Toothfish catch limit divided across SSRUs C, D, E and F in Subarea 88.2

Table 4: Distribution of pelagic bioregions across CCAMLR statistical areas.

Area	Pelagic bioregions											No. bioregions per area
	1	2	3	4	5	6	7	8	9	10	13	
48.1			X	X	X	X					X	5
48.2				X	X	X					X	4
48.3		X	X	X	X	X				X		6
48.4			X	X	X	X	X				X	6
48.5					X	X	X				X	4
48.6			X	X	X	X	X				X	6
58.4.1			X	X	X	X	X					5
58.4.2					X	X	X					3
58.4.3a			X	X	X							3
58.4.3b				X	X	X	X					4
58.4.4			X	X	X							3
58.5.1	X	X	X							X		4
58.5.2			X	X						X		3
58.6	X	X	X					X	X	X		6
58.7	X	X	X					X	X			5
88.1			X	X	X	X	X				X	6
88.2			X	X	X	X	X				X	6
88.3			X	X	X	X	X					5
No. subareas where bioregion occurs	3	4	14	13	14	12	9	2	2	4	7	
Total area as % of Convention Area	2.0	2.5	13.7	28.7	31.7	5.6	1.3	0.3	0.1	0.8	13.3	

Pelagic Bioregions:
1. Southern Temperate
2. Subantarctic Front
3. Polar Front
4. Southern ACC Front
5. Antarctic open ocean
6. Antarctic shelves
7. Antarctic shelf, slope, BANZARE Bank
8. Campbell Plateau, Patagonian shelf, Africana Rise
9. Inner Patagonian shelf, Campbell and Crozet Islands
10. Kerguelen, Heard and McDonald Islands
13. Weddell gyre and Ross Sea banks

Table 5: Proportions of the major bioregions which have established fisheries for krill and toothfish (including exploratory fisheries where catch limit is currently 0), and coverage of bioregions by MPAs. (Bioregions 1, 8, 9 and 10 are not included, as they account for less than 2% of the Convention Area).

Bioregion		% of bioregion area open to krill fishing in the 2010/11 season	% of bioregion area open to exploratory fishery for toothfish (including areas where catch limit = 0)	% of bioregion area included within MPAs
2	Subantarctic Front	10	10	0
3	Polar Front	23	56	0
4	Southern ACC Front	36	58	0
5	Antarctic open ocean	31	72	0
6	Antarctic shelves	31	75	1.2
7	Antarctic shelf slope	17	94	0
13	Weddell and Ross gyres	14	32	1.5

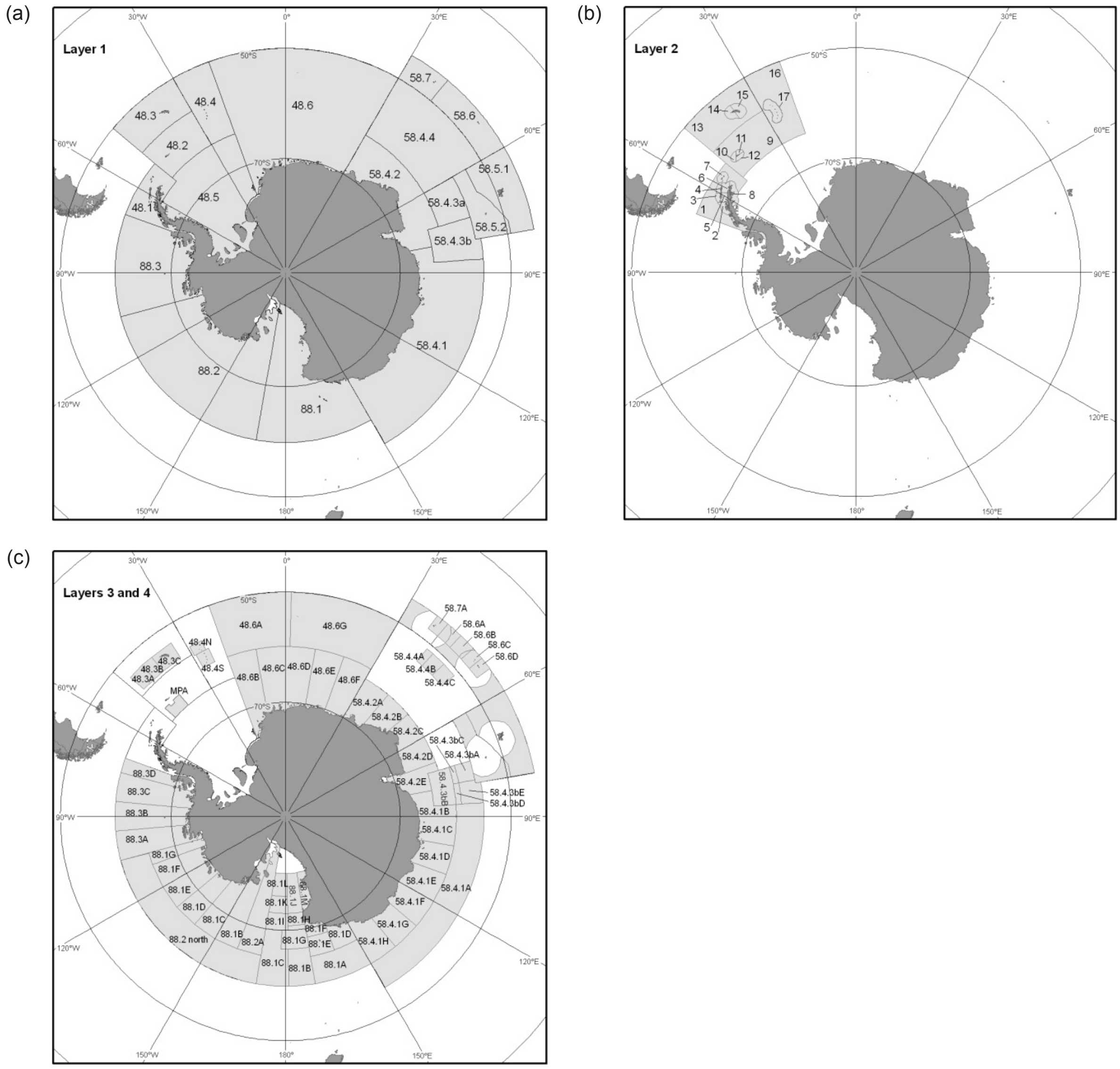

Figure 1: Spatial information contained in the GIS database: (a) CCAMLR statistical subareas (layer 1); (b) small-scale management units (SSMUs) (layer 2); (c) small-scale research units (SSRUs) and other fisheries management units (layer 3) and marine protected areas (MPAs) (layer 4). See Table 3 for catch limits in each area.

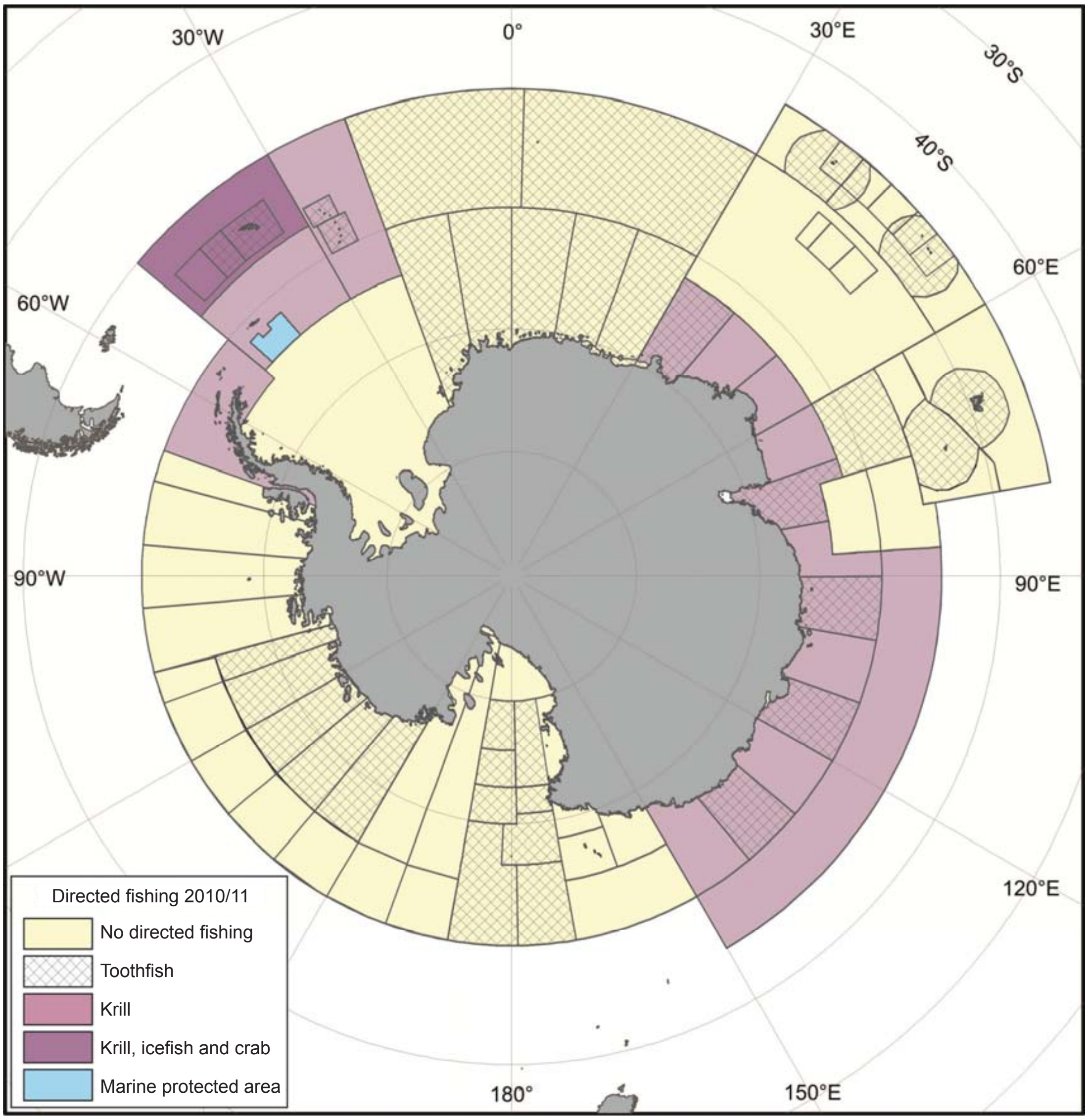

Figure 2: Directed fishing for toothfish, icefish, krill and crabs, subject to seasonal limits and closures in 2010/11. This reproduction of a map shown in CCAMLR (2010) was generated by querying the GIS database.

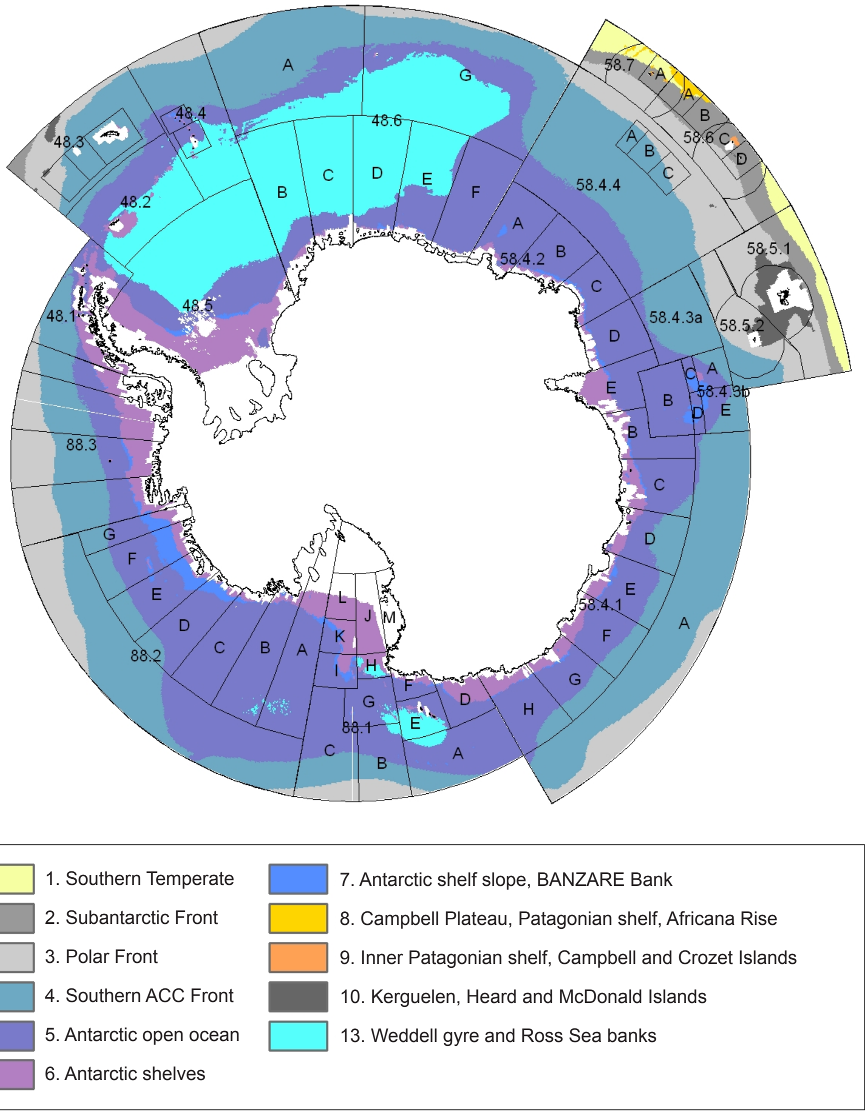

Figure 3: Primary pelagic bioregions (Grant et al., 2006), clipped to the extent of the CAMLR Convention Area, and overlaid with spatial data on subareas and other fisheries management areas from the GIS database. Three of the 14 pelagic bioregions originally defined by Grant et al. (2006) (11 Subtropical Front; 12 Northern Temperate and 14 Chatham Rise) do not occur within the Convention Area.

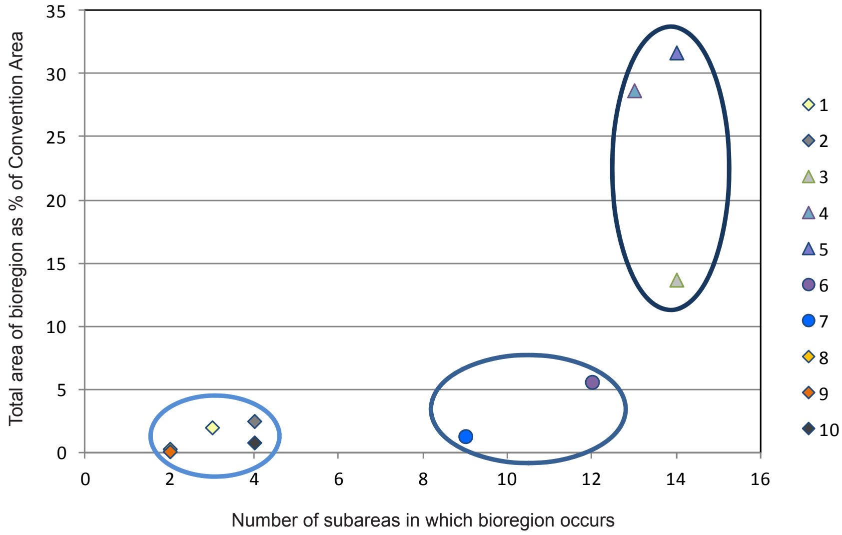

Figure 4: Distribution of pelagic bioregions across CCAMLR statistical subareas: The percentage of the total Convention Area covered by each bioregion versus the number of subareas in which each bioregion occurs. Each bioregion is represented by a different symbol (colours correspond to the legend in Figure 5). Large ovals indicate groups of bioregions with similar distributions across the Convention Area.

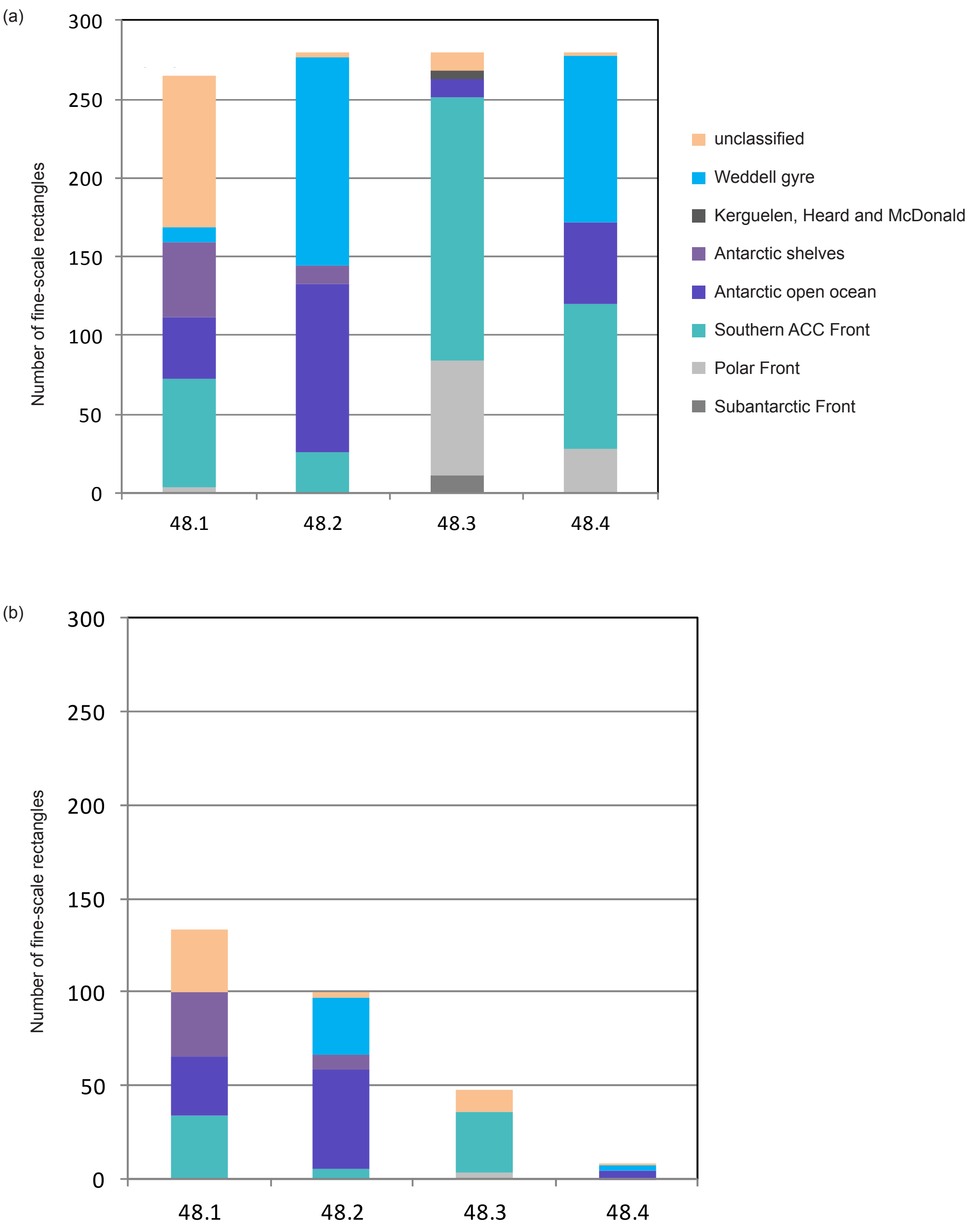

Figure 5: Spatial overlap between bioregions and krill catch for subareas in Area 48 that are open to krill fishing: (a) number of fine-scale (1° × 0.5°) rectangles by bioregion, (b) number of fine-scale rectangles where aggregated krill catch for 1995 to 2010 was >0 tonnes by bioregion. Fine-scale rectangles were classified according to the bioregion with the greatest area within the rectangle.

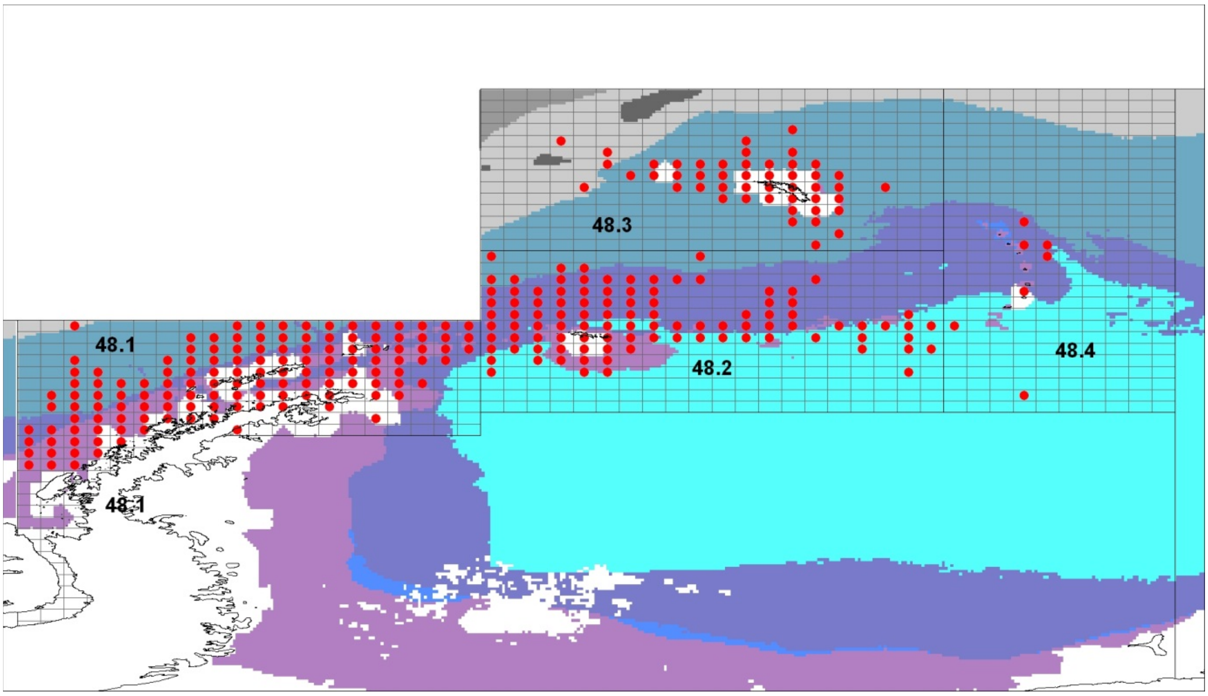

Figure 6: Spatial distribution of krill fishing across bioregions in Subareas 48.1 to 48.4. Red dots indicate fine-scale rectangles in which aggregated krill catch for 1995 to 2010 was >0 tonnes.

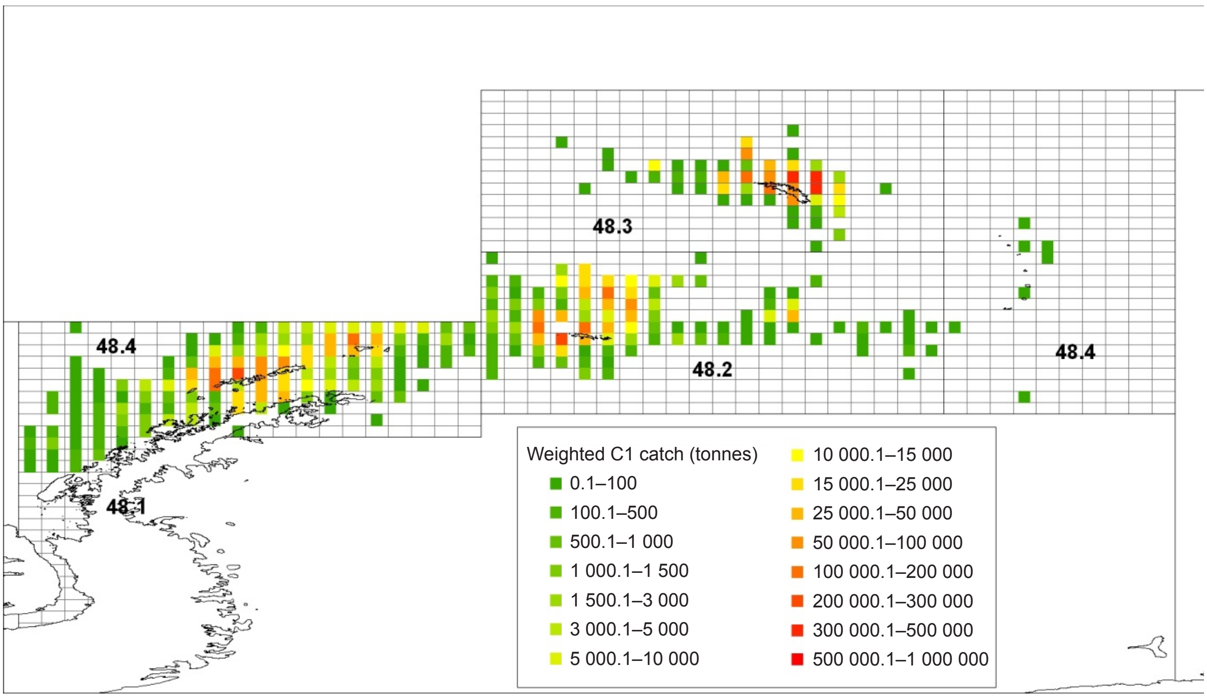

Figure 7: Spatial distribution of krill catch within Subareas 48.1 to 48.4 (weighted C1 catch = haul-by-haul data reported within the fine-scale rectangles, rescaled to sum to the official reported catch by subarea. The data are totals for the years 1995 to 2010).